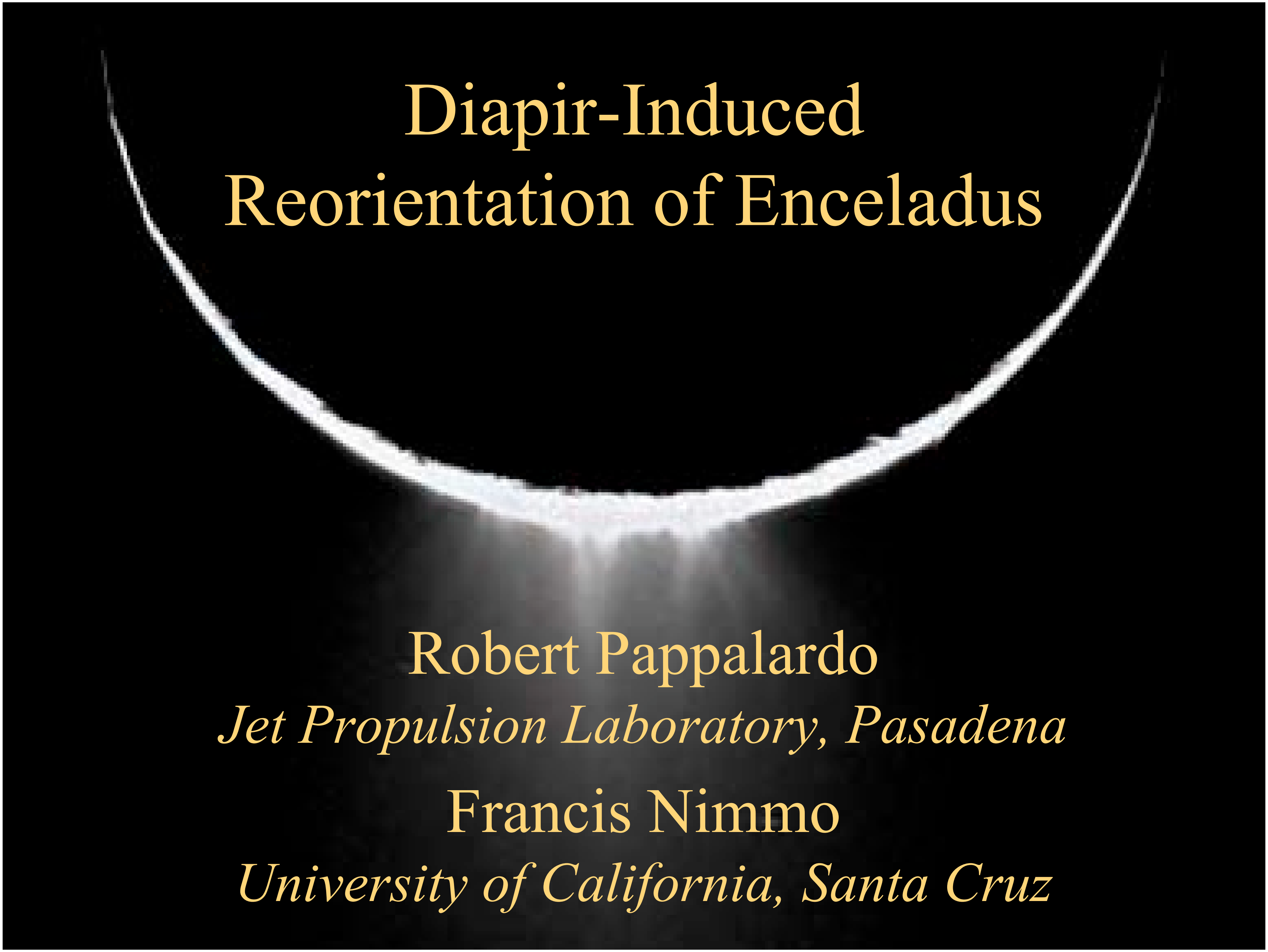

Diapir-Induced Reorientation of Enceladus

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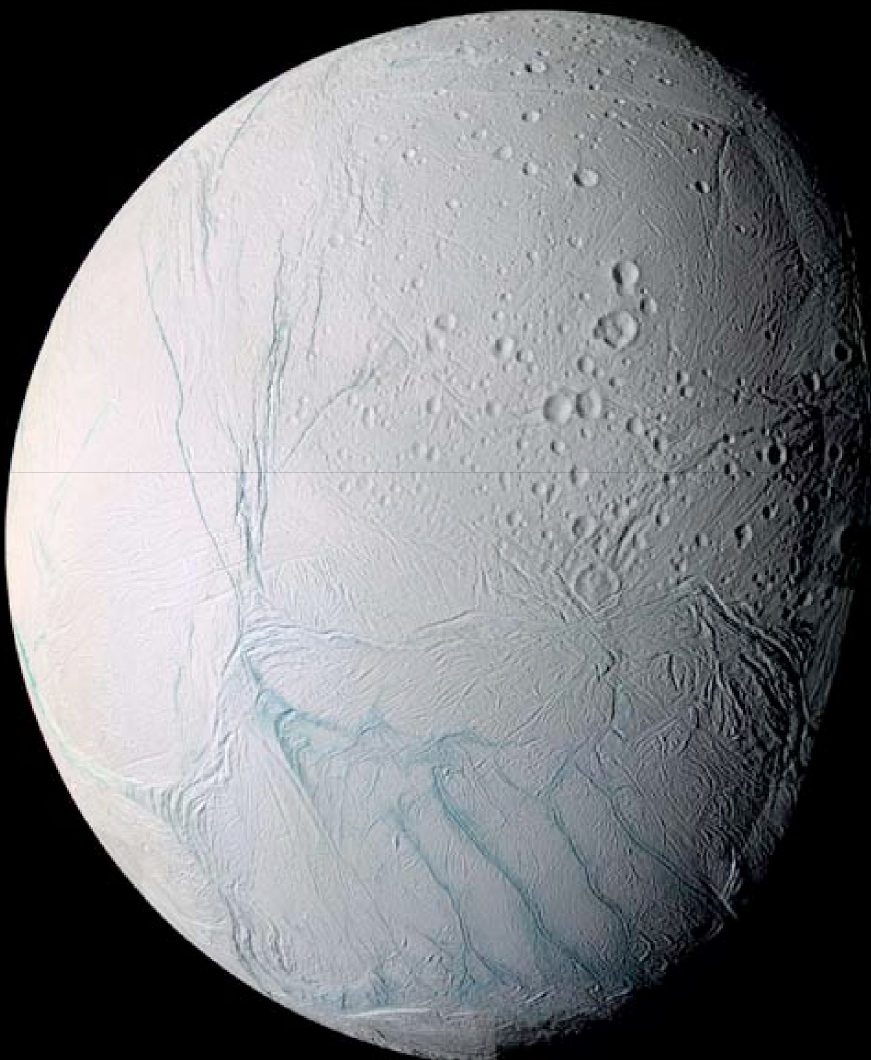
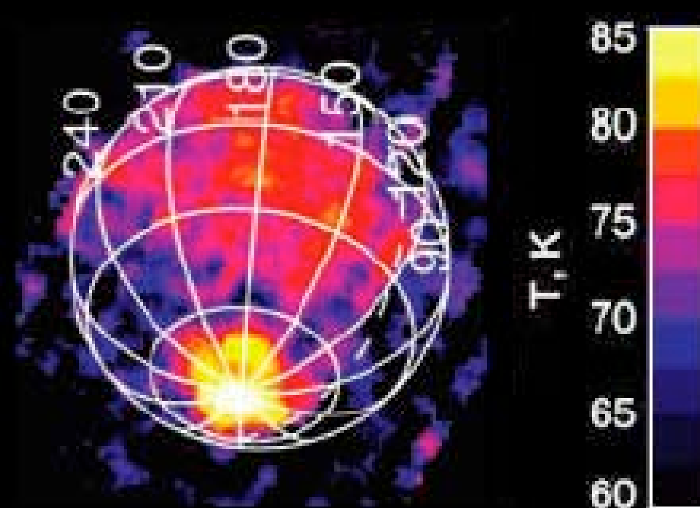
Activity on Enceladus

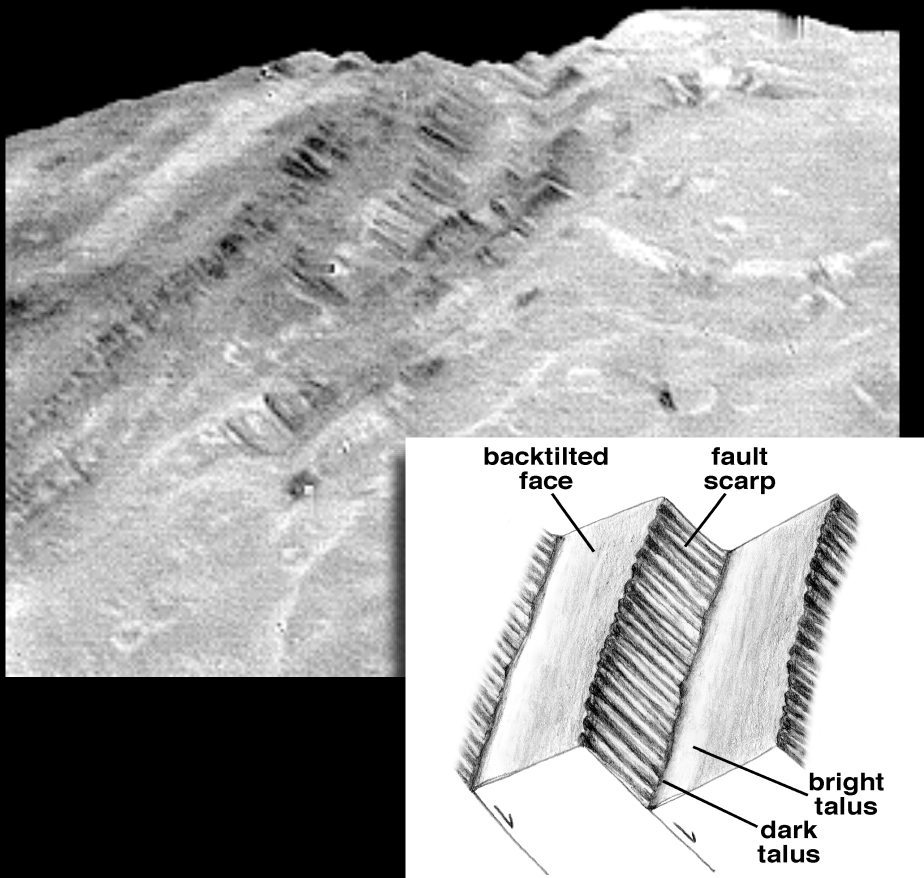


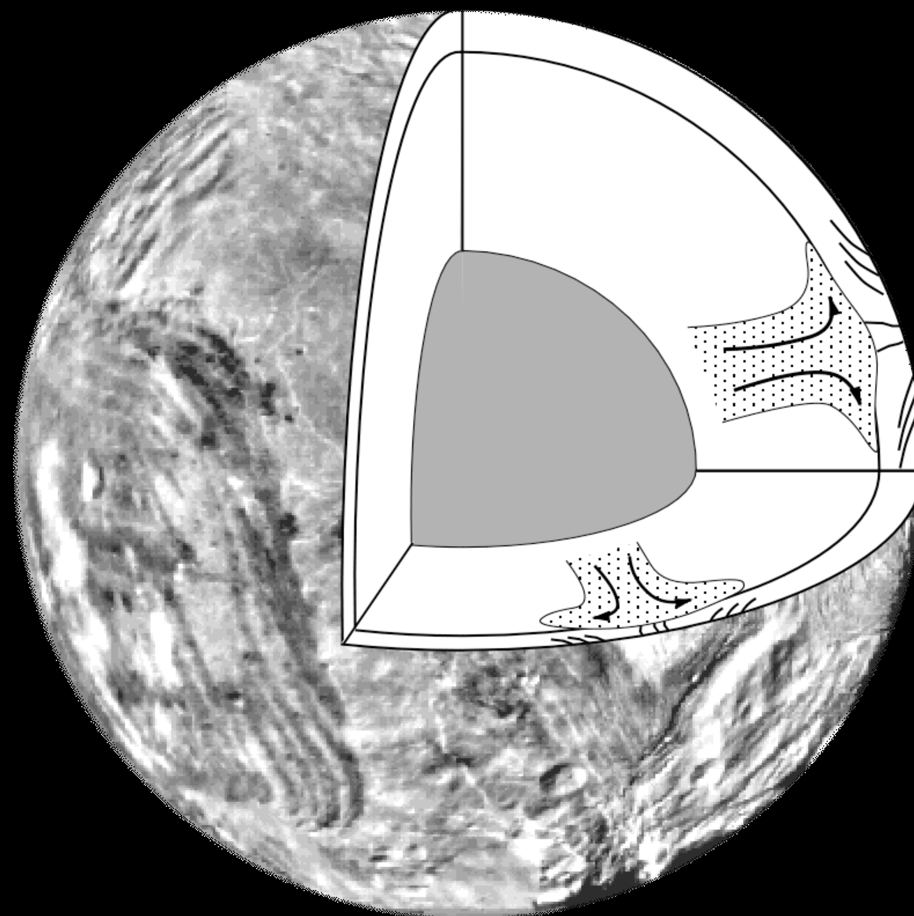
- Region of thermal and tectonic activity centered at south pole [*Porco et al., 2006; Spencer et al., 2006*].
- Presumed tidal heat source [*Ross & Schubert, 1989; Matson et al., this meeting*].



Miranda's Coronae: Origin above Diapirs

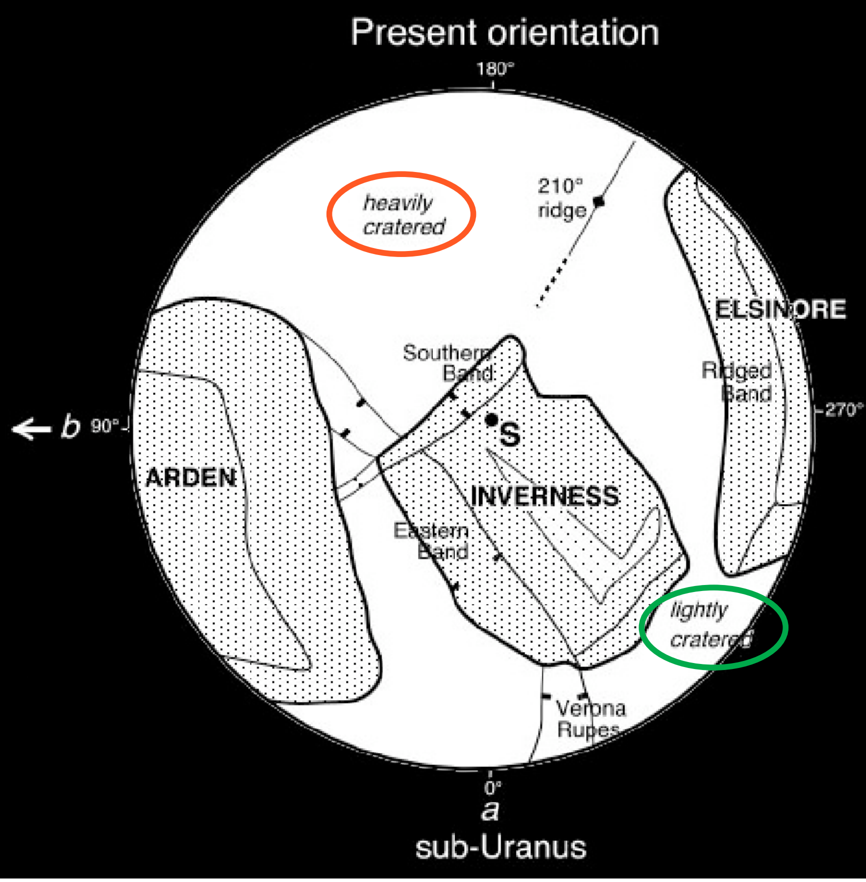
- Extensional structures and cryovolcanism suggest coronae formed above upwelling diapirs [*Johnson et al., 1987; Greenberg et al., 1991; Pappalardo et al., 1997*].

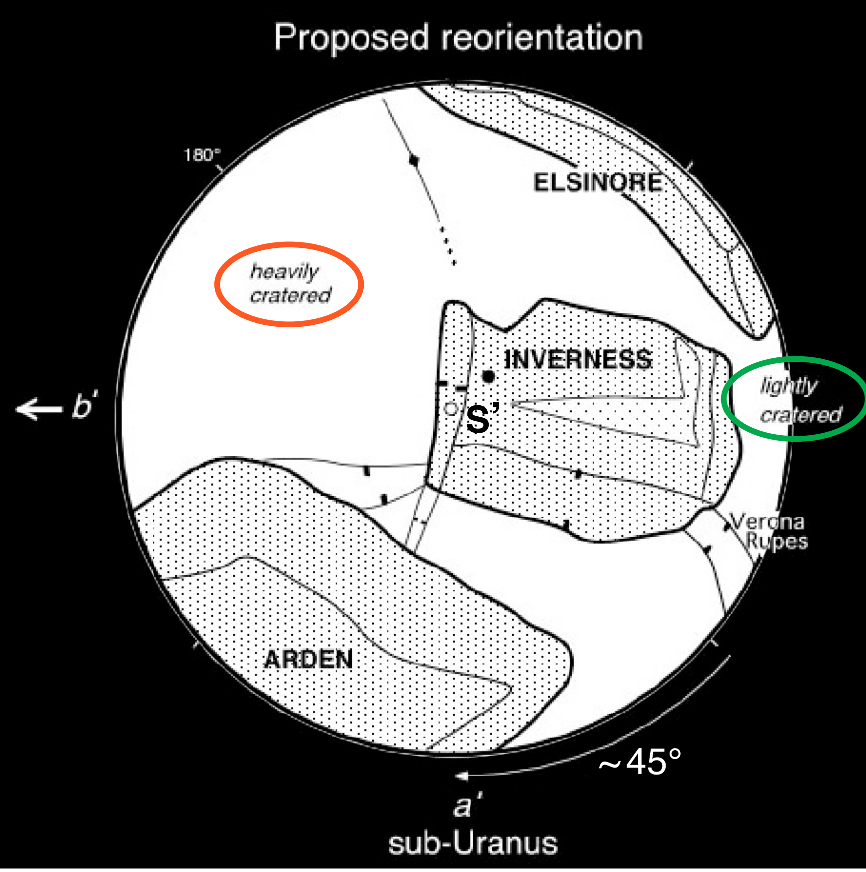




Reorientation of Miranda

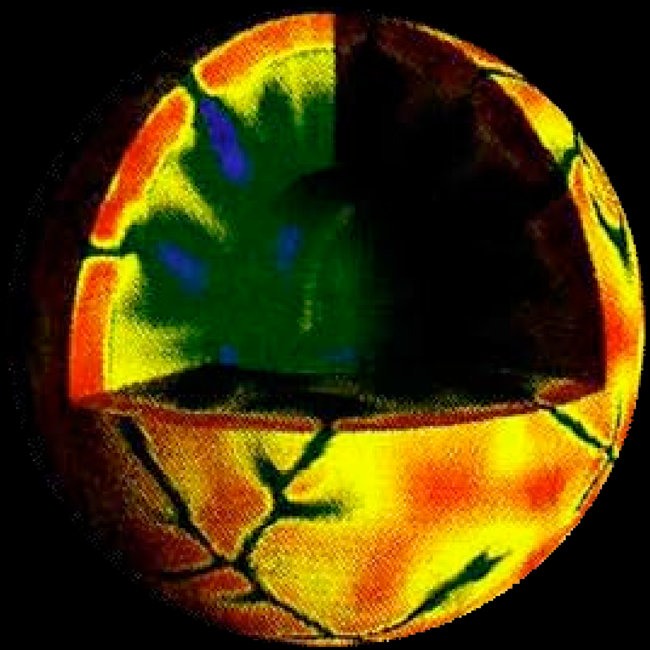
- Coronae on greatest inertia axes (south pole, leading/trailing) suggests reorientation to place mass deficiencies there [*Janes & Melosh, 1988; Greenberg et al., 1991*].
- Supported by craters and structures [*Plescia, 1988; Pappalardo, 1994*].





Planetary Reorientation

- *Earth:* Mantle convection can alter mass distribution to induce true polar wander (TPW), including inertial interchange events [*Richards et al., 1997, 1999*].
- *Mars:* Tharsis would reorient to equator [*Willemann, 1984; Bills and James, 1999; Sprenke et al., 2005; Matsuyama et al., 2006*], and dichotomy boundary to pole [*Roberts & Zhong*, in press].

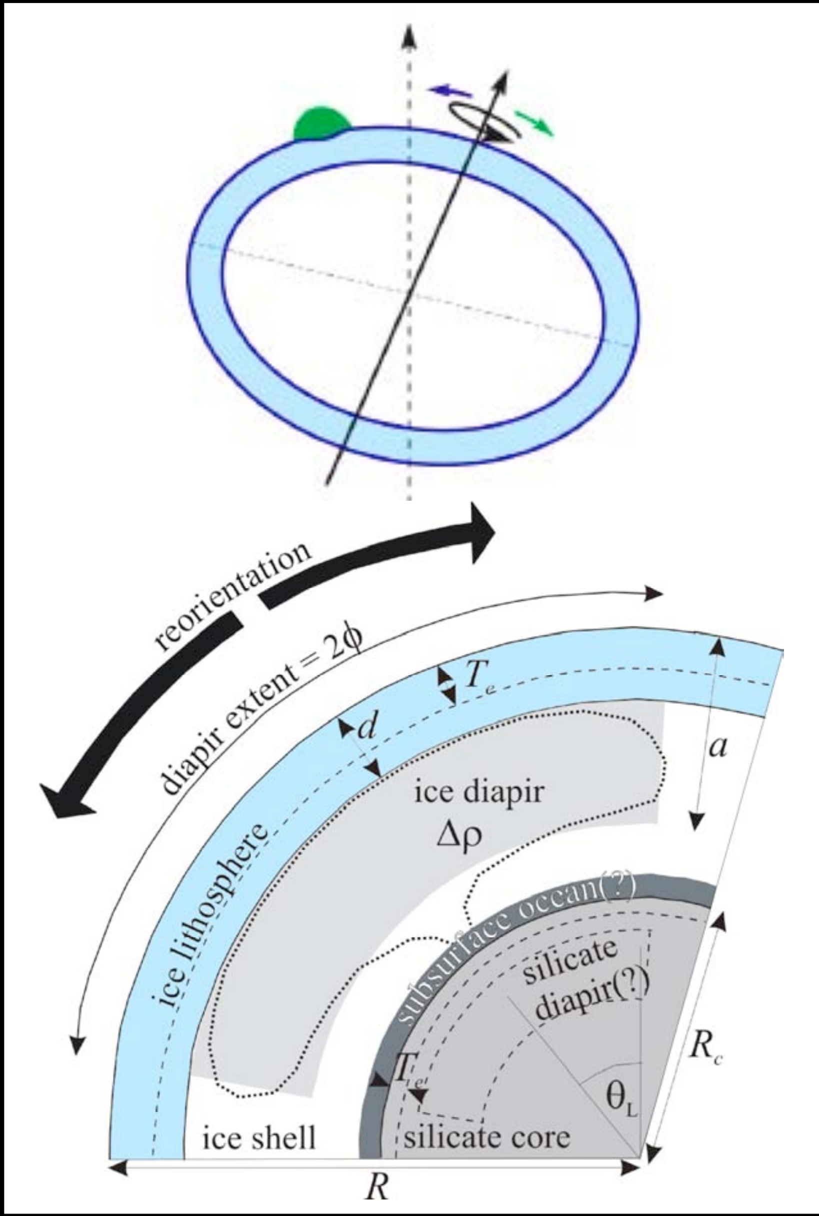


[*Richards et al., 1997*]

[*Roberts & Zhong, this meeting*]

Modeling Diapir-Induced Reorientation

- Adapt methods of *Matsuyama et al. (2006)*:
  - ◊ Balance between load-induced TPW and stabilization by fossil rotational **and tidal** bulges.
  - ◊ Lithospheric rigidity affects both fossil bulge size and load compensation *C*, thus TPW.
  - ◊ Uncompensated low-density diapir (*C*=0) is **negative** geoid anomaly: reorients **poleward**.
  - ◊ If compensated (*C*=1), upwarped topography is **positive** geoid anomaly: reorients **equatorward**.

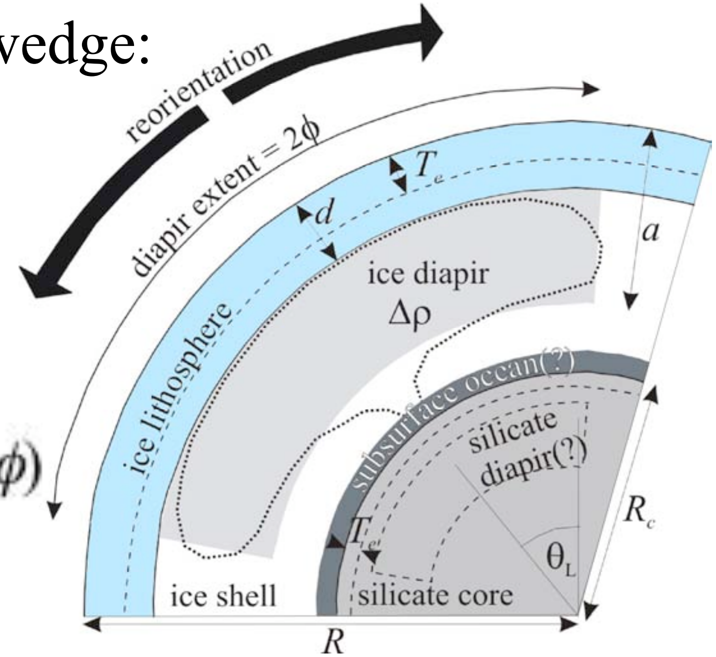


Modeling Diapir-Induced Reorientation

- Diapir modeled as low-density spherical wedge:

$$2\pi R_t^{\,2}\Delta\rho(a-d)(1-\cos\phi)\left\{1-\frac{a+d}{R_t}+\frac{e^2}{3R_t^{\,2}}\right\}$$

ϕ = angular radius of diapir
$e^2 = a^2 + ad + d^2$; assume $T_e = 0.4\ d$



- Mass excess at surface: $C2\pi\rho R_t^{\,2}h(1\text{-}\cos\phi)$
h = isostatic surface topography
C = degree of compensation ($0 < C < 1$)

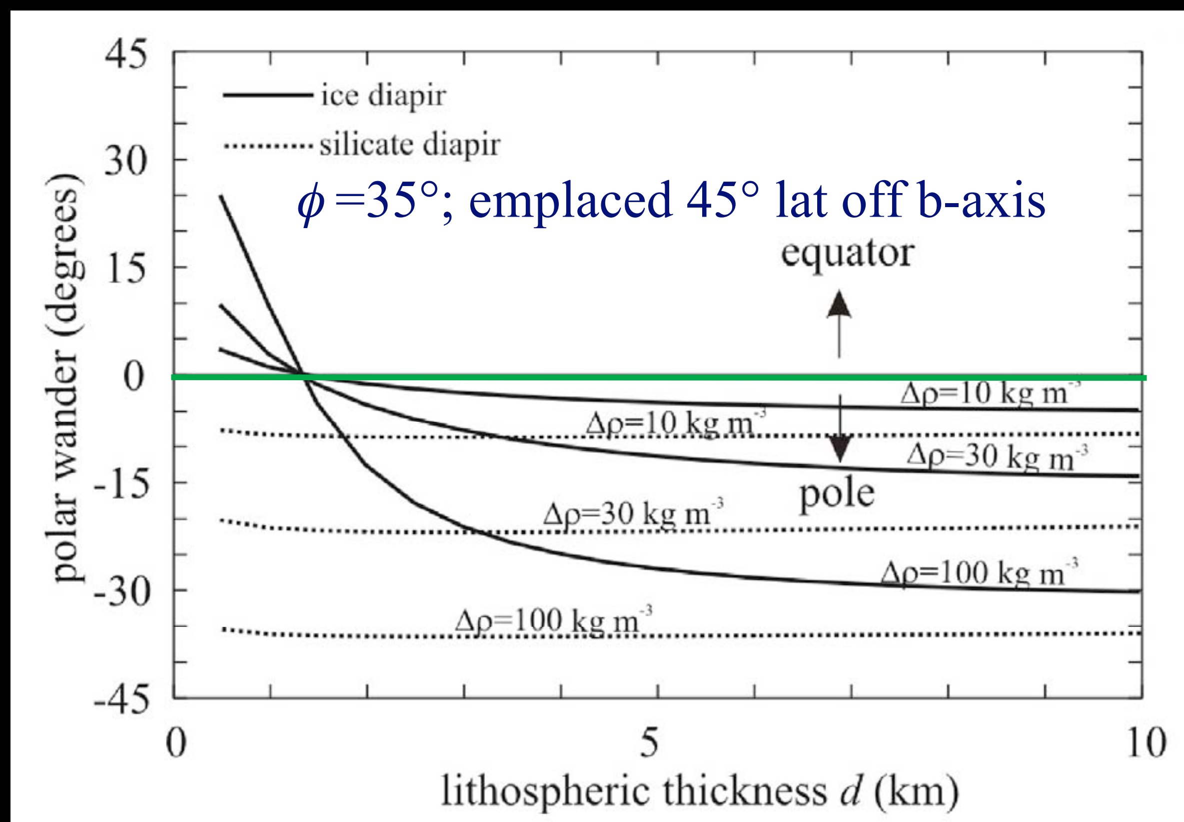
- Angular reorientation due to load: $\boxed{\delta = \frac{1}{2}\tan^{-1}\left(\frac{Q^*\sin 2\theta_L}{n - Q^*\cos 2\theta_L}\right)}$

where $Q^* = \dfrac{3\sqrt{5}G_{20}}{R^2\Omega^2(k_2^f - k_2)}$; n=1 for b-axis, n=4 for a-axis

G_{20} = degree 2 component of gravitational potential due to diapir
k_2, k_2^f = Love numbers with and without an elastic lithosphere
Ω = angular rotation rate

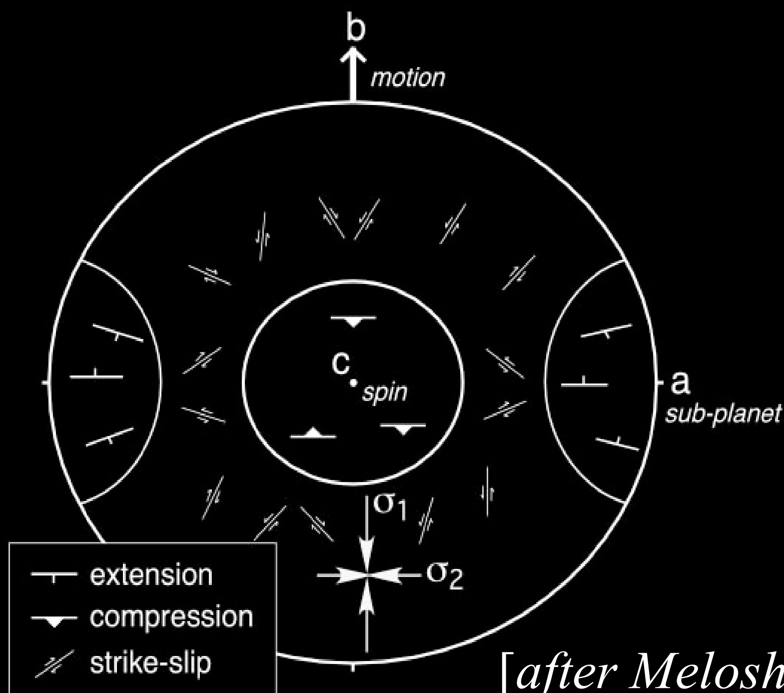
Diapir-Induced Reorientation: Results

- For **ice diapir**, poleward reorientation up to ~30° for $d > 1.5$ km:
  - ◊ Large $\Delta\rho \approx 100$ kg m^3 $\Rightarrow$ **thick ice and compositional diapirism**.
- For **silicate diapir**, similar reorientation amount ($C \approx 0$):
  - ◊ Coupling to ice $\Rightarrow$ **no global ocean**.
- Reorientation is dependent on emplacement location.
- Results insensitive to k_2.
- Greater reorientation if silicate diapir triggers ice diapir.

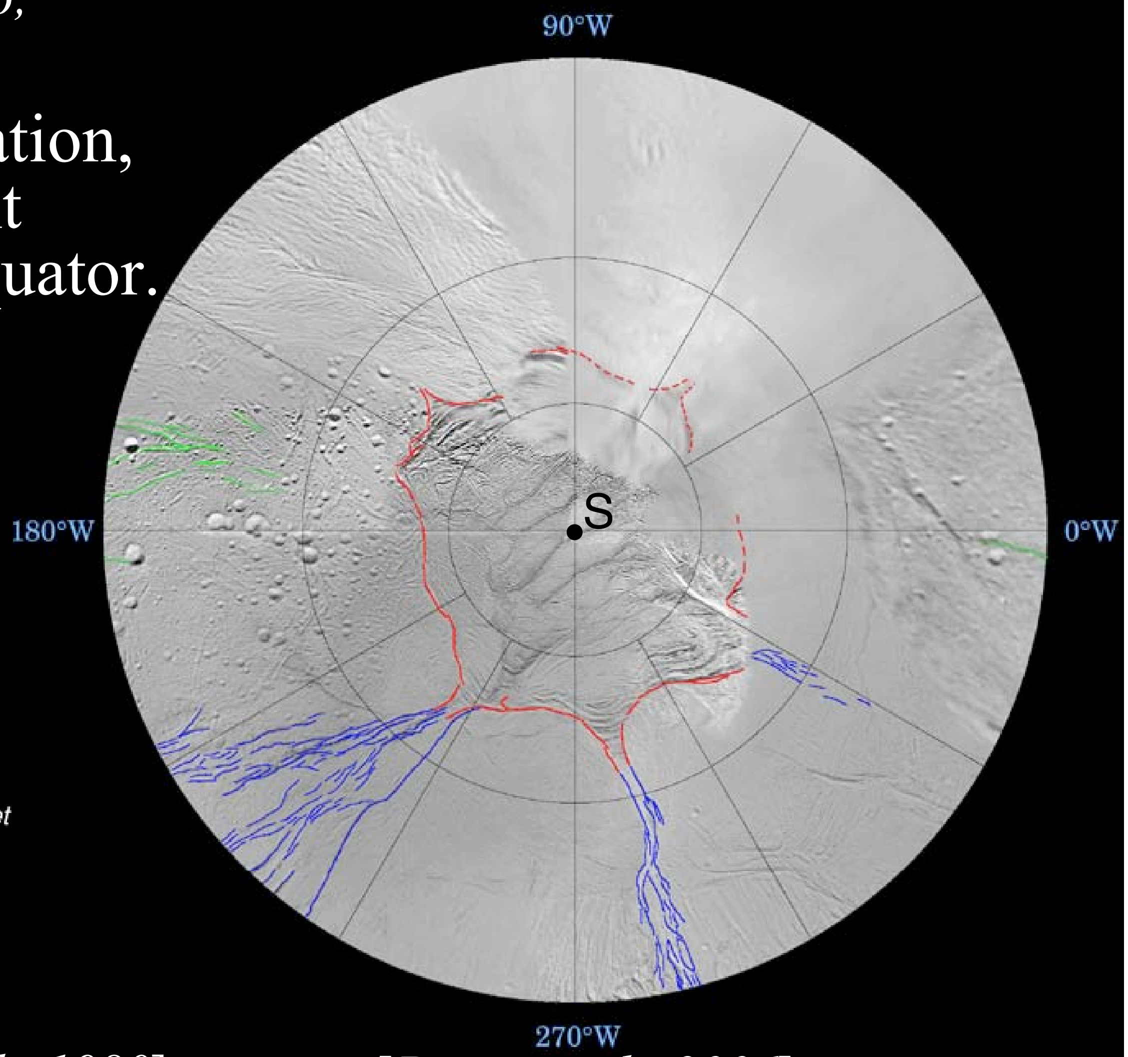


Tectonic Implications of Reorientation

- Tectonics suggest spin axis flattening [*Porco et al., 2006; Helfenstein et al., this meeting*].
- Consistent with reorientation, which "squashes" current spin axis and expands equator.
- Stresses ~10 MPa.



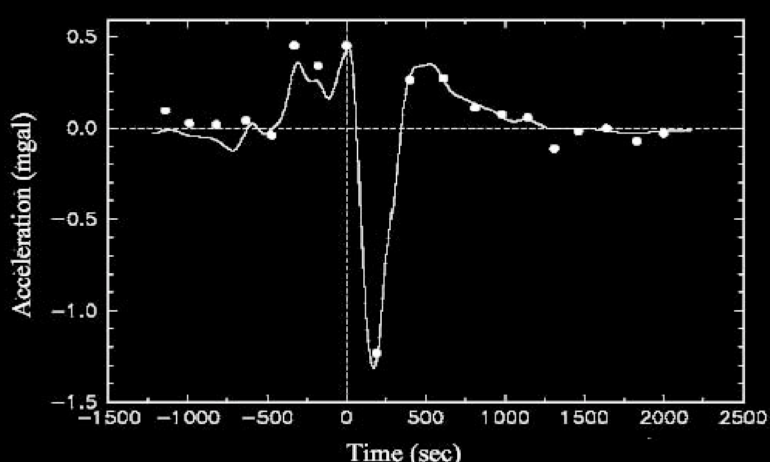
[*after Melosh, 1980*]

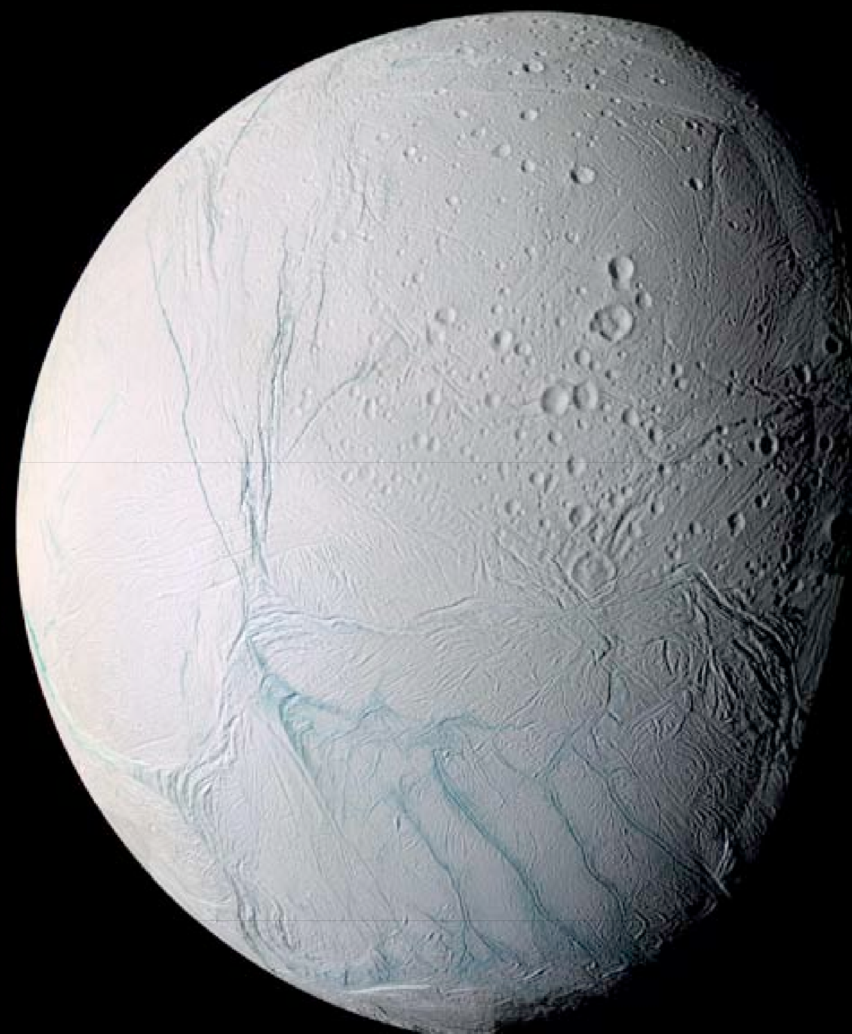


[*Porco et al., 2006*]

Additional Tests of Reorientation

- Reorientation should affect crater distribution by affecting leading-trailing asymmetry:
  - ◊ Decipherable from imaging.
- Gravity anomaly should be associated with diapir:
  - ◊ A few mGal from 200 km.
  - ◊ Similar anomalies detected at Ganymede by Galileo.

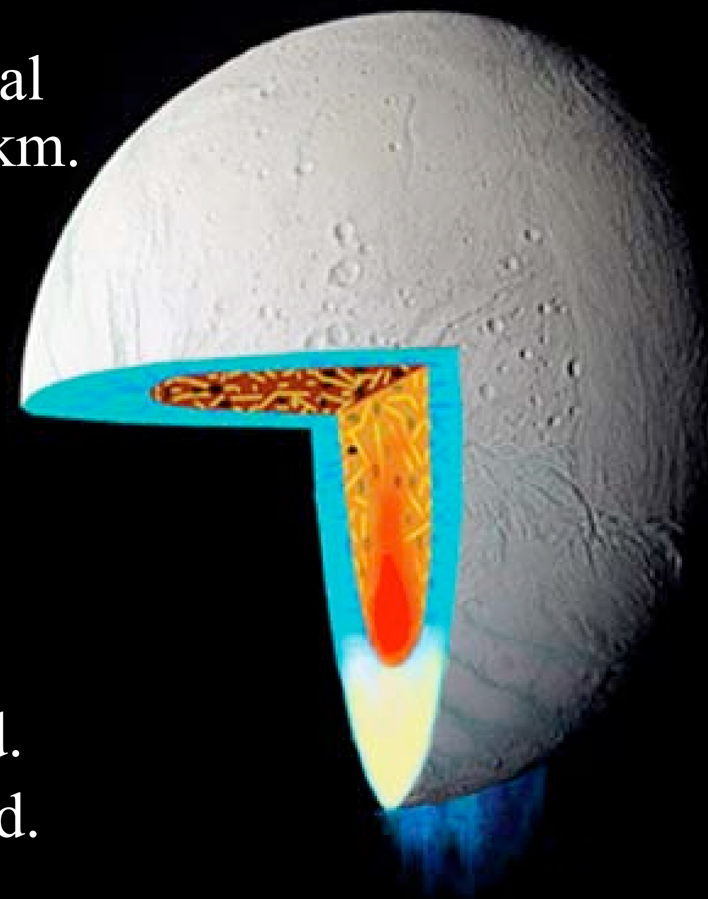




[*Palguta et al., 2006*]

Diapir-Induced Reorientation of Enceladus: Conclusions

- Large diapir can reorient active region to south pole:
  - ◊ Ice diapir ⇒ thick shell, compositional buoyancy, rigid lithosphere $T_e > 0.5$ km.
  - ◊ Silicate diapir ⇒ no global ocean.
  - ◊ These may combine.
  - ◊ But Enceladus cannot have both a thin ice shell and a global ocean.
- Tests of diapir-induced reorientation:
  - ◊ Tectonic record: polar flattening!
  - ◊ Cratering record: asymmetry affected.
  - ◊ Gravity: detectable anomaly predicted.



Diapir-Induced Reorientation: Future Work

- Origin and nature of large diapirs.
- Relative timing of diapir rise, lithosphere thickness, tidal heating, and reorientation.
- Multiple heating-diapir episodes?
- Effect of emplacement position.
- Consideration of other mid-sized icy satellites.
- Miranda’s apparent a→b-axis reorientation, and timing of corona formation.
- Future Cassini tests for Enceladus.